Half-day meeting devoted to the Second

1. The second in the revised SI
2. Impact of the redefinition of the second in the concerned communities:
    a. IAU (International astronomical union)
    b. URSI (International union of radio science)
    c. IUGG (International union of geodesy and geophysics)
    d. IUT (International telecommunication union)
3. Timescales, clocks, time and frequency comparisons
4. Roadmap towards the redefinition of the second

Bureau International des Poids et Mesures

The Second in the Revised SI

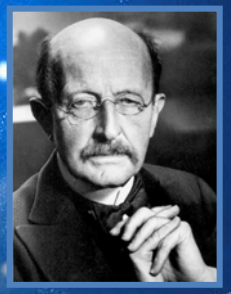
The Second in the Revised SI

SI International System of Units

The SI second:
$\Delta\nu_{Cs}$ = 9 192 631 770 Hz

Since 1967

- **The first SI quantum standard**
- **The only one to be redefined in the future**



…for all times and civilisations…

…throughout the Universe…

to the Quantum SI

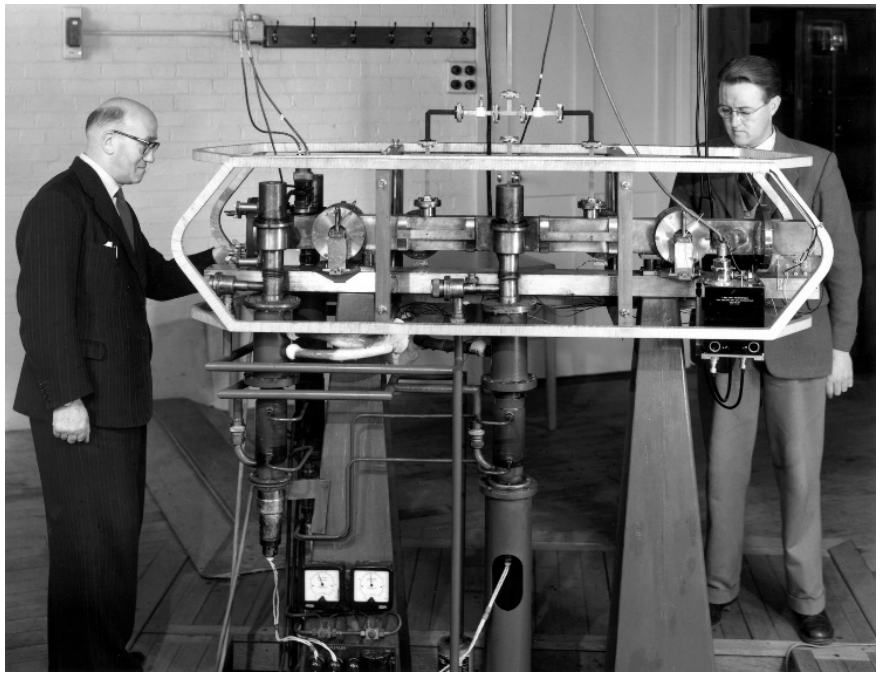
Thermal beam cesium clocks

- generation of atom beams in vacuum
- excellent transverse momentum resolution
- quantized orientation of angular momentum

→ Molecular beam and microwave resonance, 1938 (I. I. Rabi)

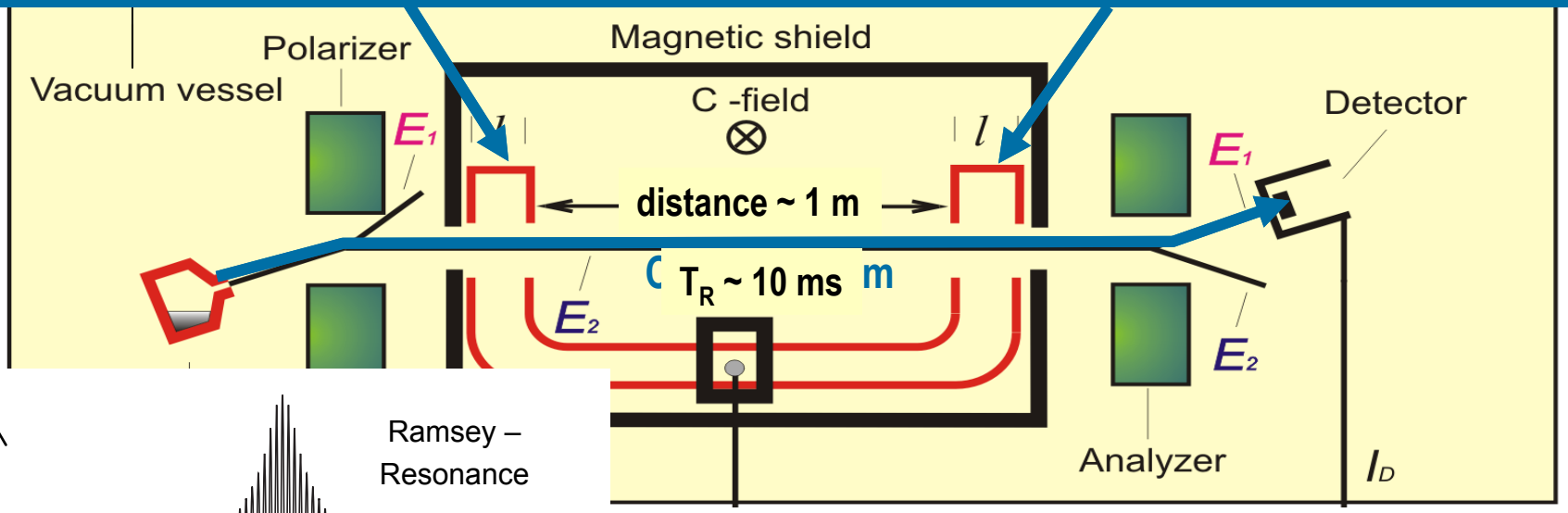
→ First thermal beam cesium clock: NPL (L. Essen and J. V. L. Parry), 1955

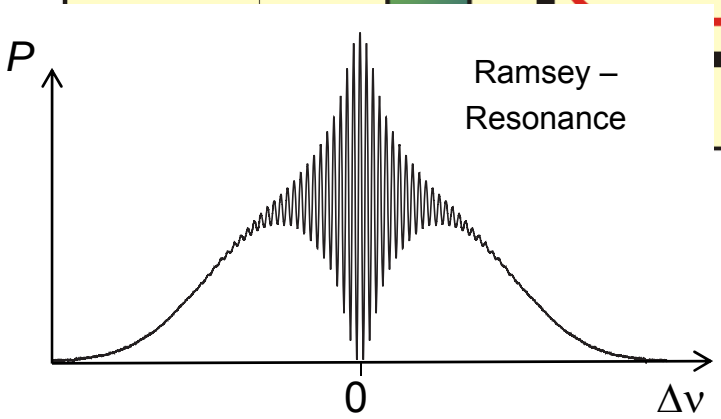
Stern-Gerlach, 1922



Thermal beam cesium clocks

2 microwave interactions with T_R time separation: Reduced resonance linewidth

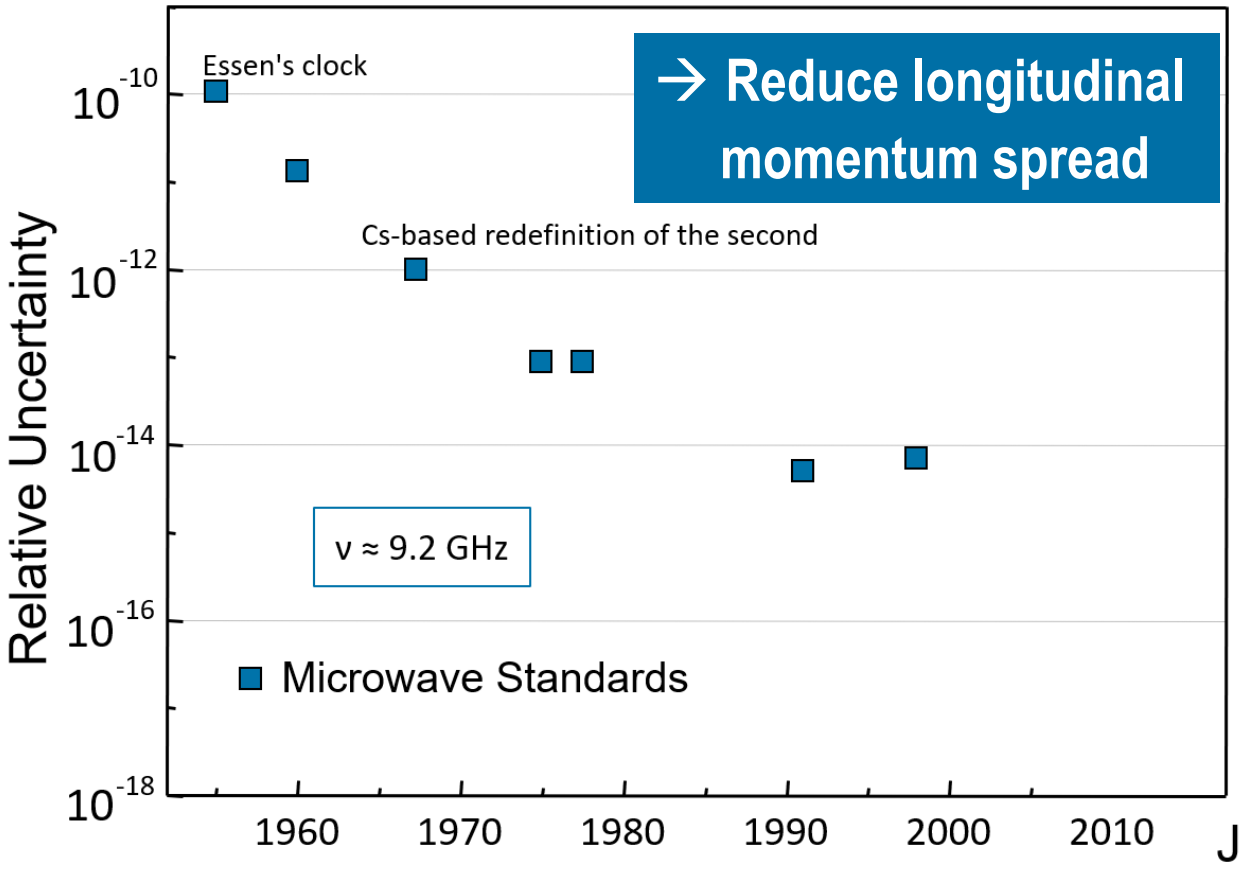




→ linewidth (FWHM) = ½ T_R

→ precision limit: ~10^{-14} (T_R)

Thermal beam cesium clocks



PTB-CS2 (1985):

The Magneto-Optical Trap (MOT)

→ 3D trapping and cooling

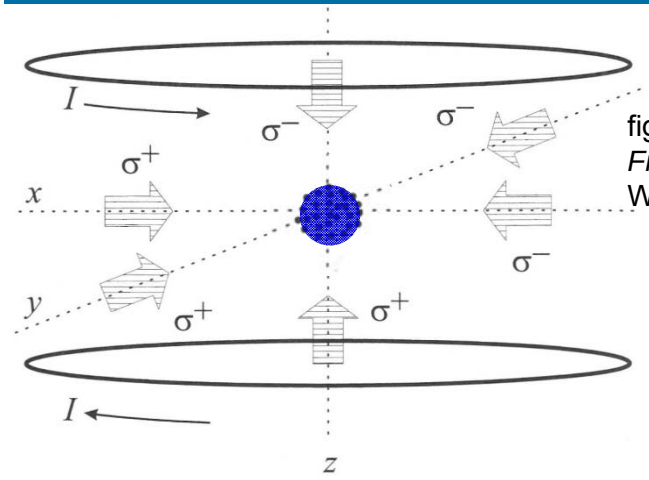


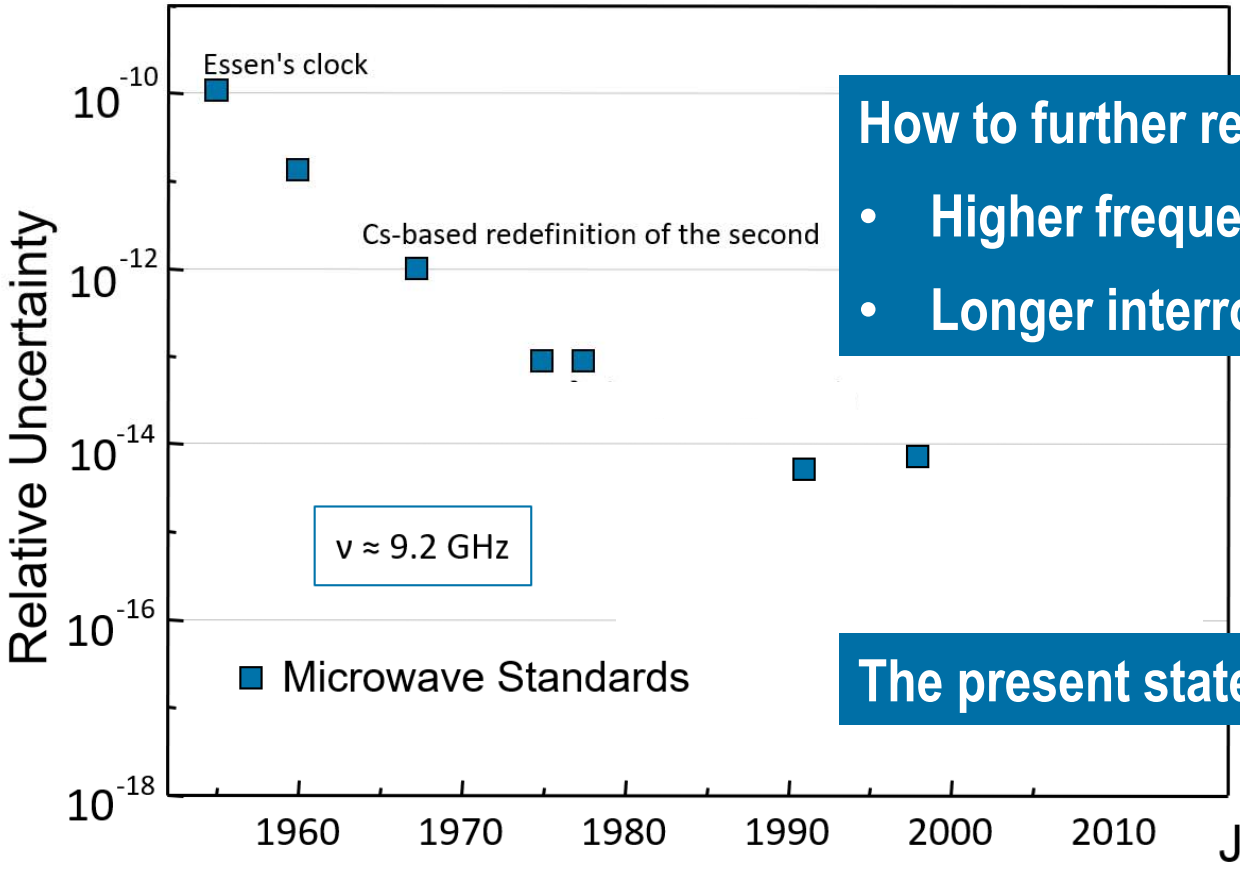
figure from F. Riehle, *Frequency Standards*, Wiley-VCH

- 3 orthogonal pairs of counter-propagating laser beams
- a spherical quadrupole magnetic field (pair of anti-Helmholtz coils)

→ harmonic potential for trapping the atoms

→ Atomic fountain clock

The Magneto-Optical Trap (MOT)

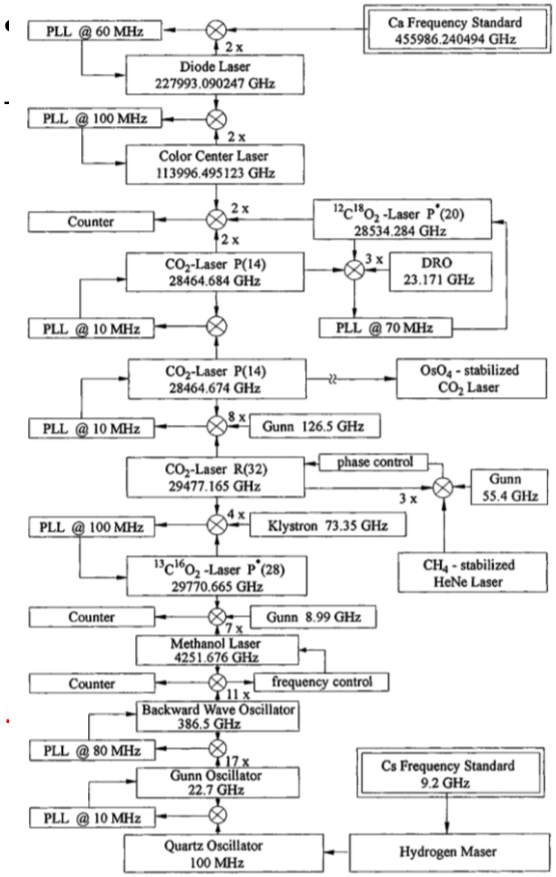


How to further reduce the uncertainty?

- **Higher frequencies → frequency comb**
- **Longer interrogation times → traps**

The present state of the art of the SI second

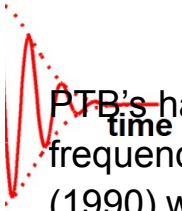
Frequency combs



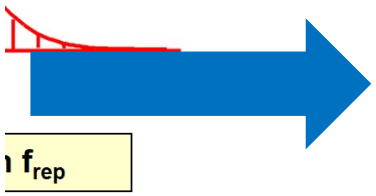
frequency comb generator:

fixes the frequencies of all modes

Frequency chains



PTB's harmonic frequency chain lab (1990) with IR gas lasers

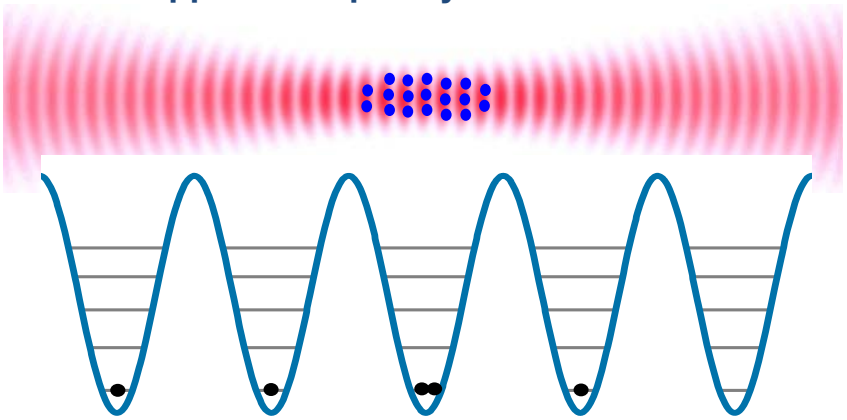


Roy Glauber,
John Hall,
Theodor Hänsch
Nobel prize 2005

Traps for clocks

Atom traps

- Large number of atoms (n ~ 10^3)
  → **High stability**
- Requires laser cooling (T ∽ μK)
- Optical lattice → **Strong confinement**
- "Magic" Wavelength
  → **Suppress frequency shift of clock transition**



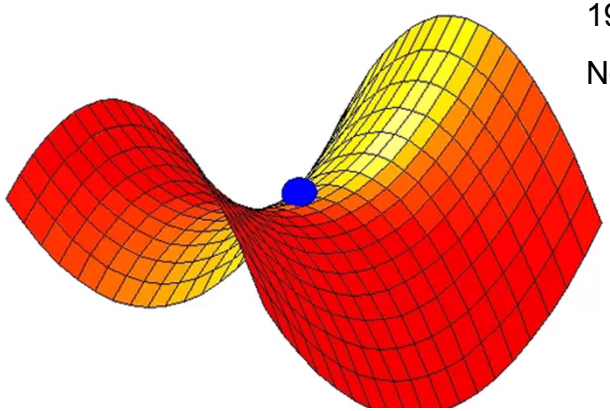
Ion traps

- Uses RF-quadrupole-fields
- trap with electric fields
  → **Charged particles interact strongly with environment**
- large trap depth:
  → **storage times: days/months**

Wolfgang Paul

1913 – 1993

Nobel prize 1989



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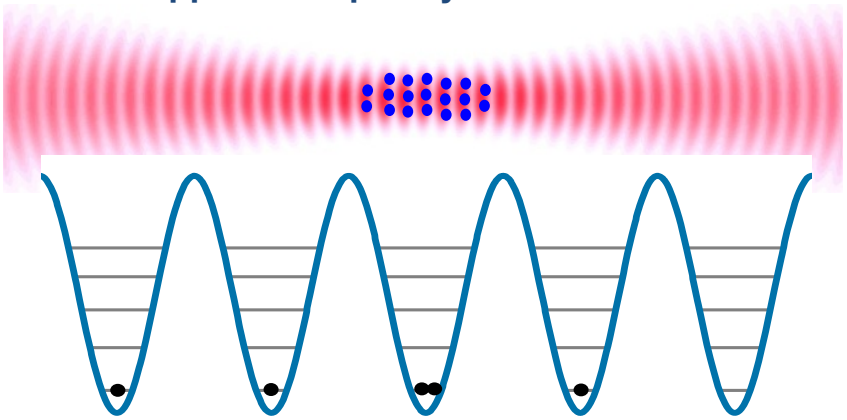
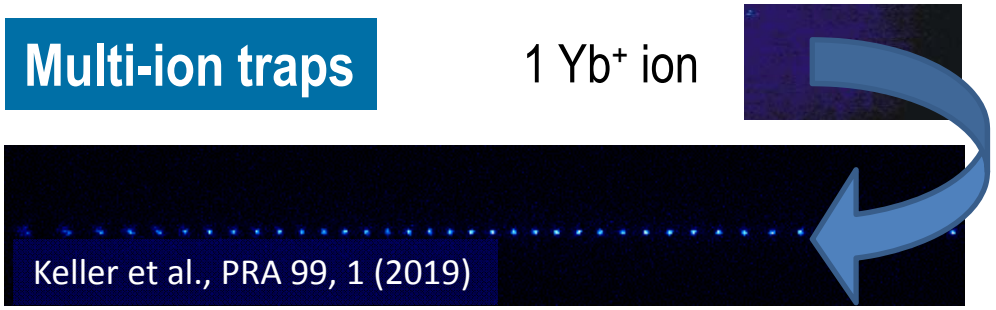
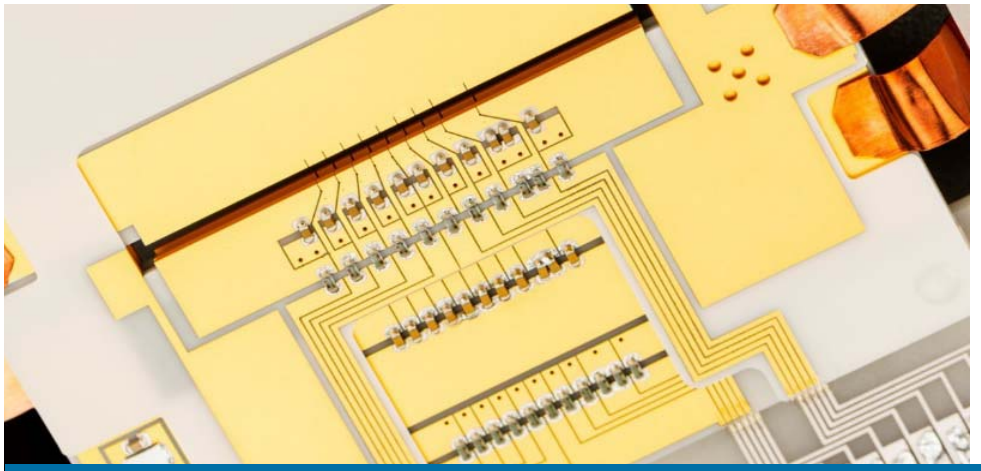


Multi-ion traps

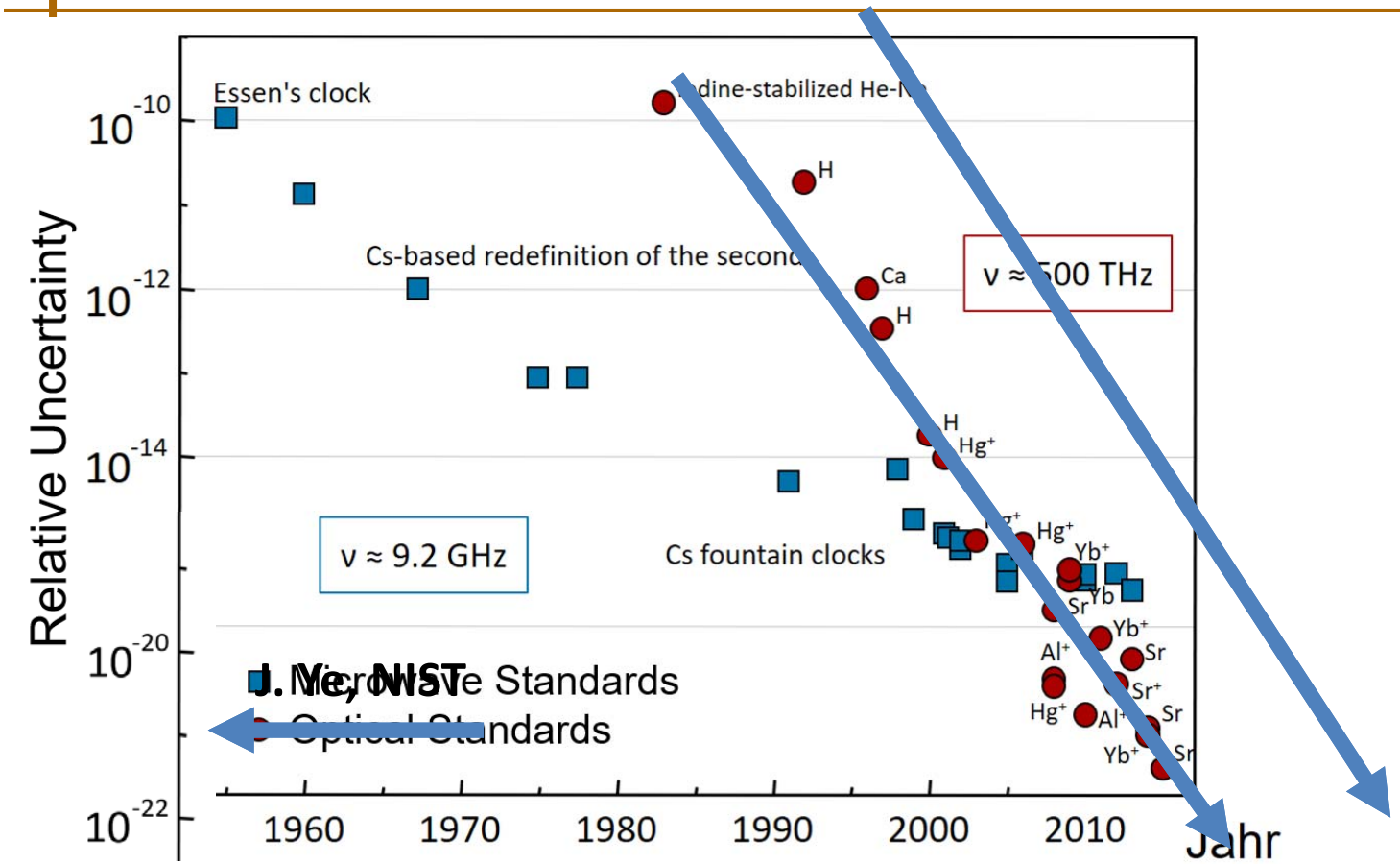
1 Yb^+ ion



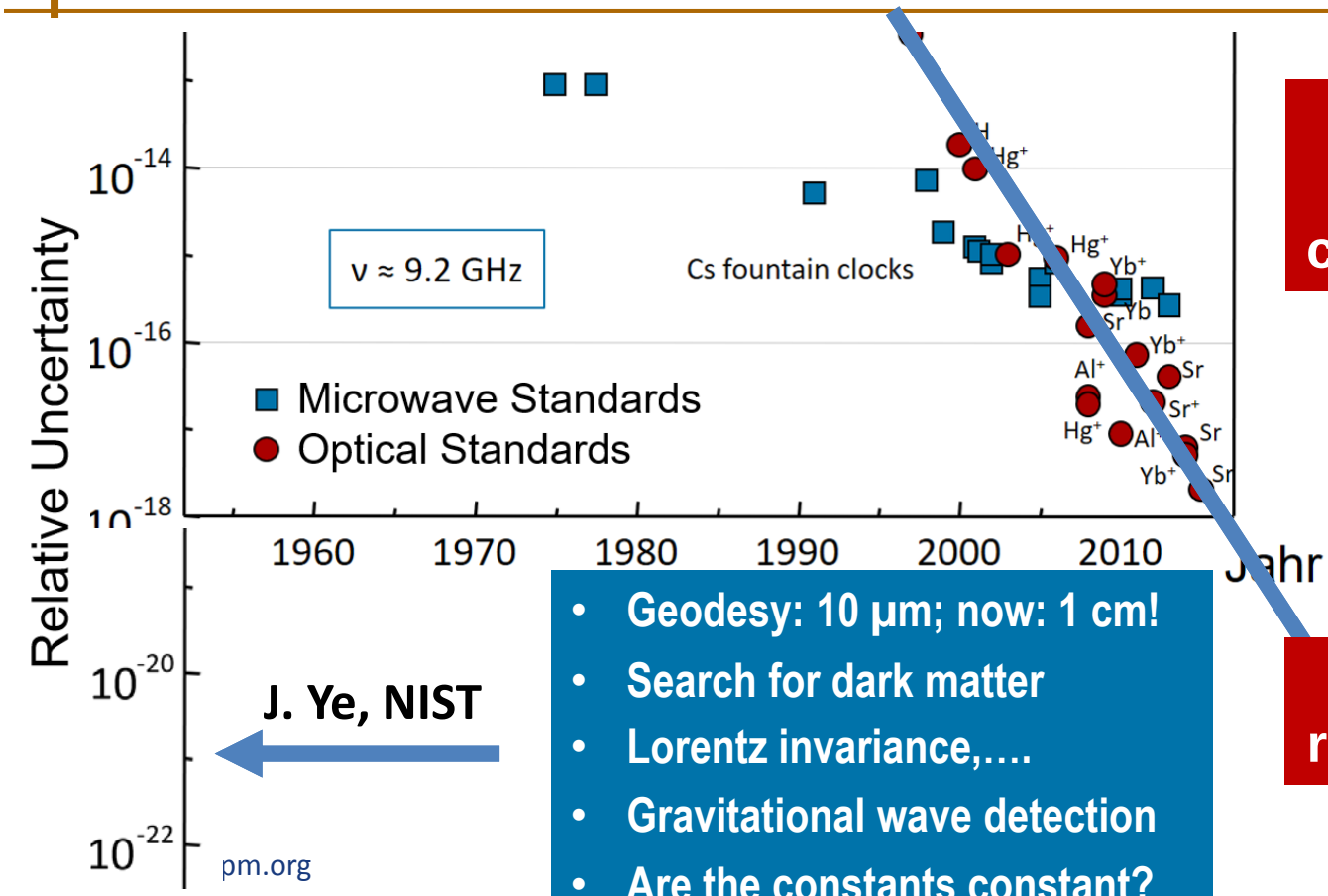


Segmented multi-ion traps: >100 ions

Optical clocks



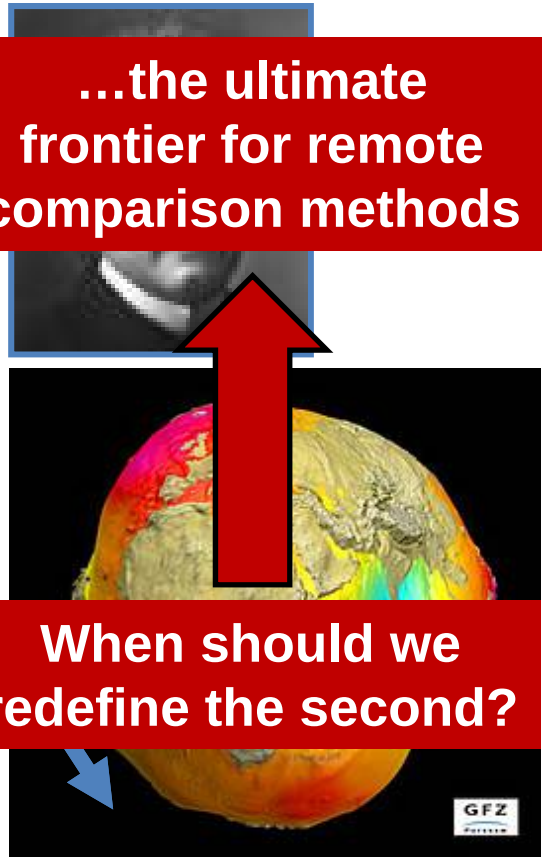
Optical clocks



J. Ye, NIST

- Geodesy: 10 µm; now: 1 cm!
- Search for dark matter
- Lorentz invariance,….
- Gravitational wave detection
- Are the constants constant?

…the ultimate frontier for remote comparison methods



When should we redefine the second?

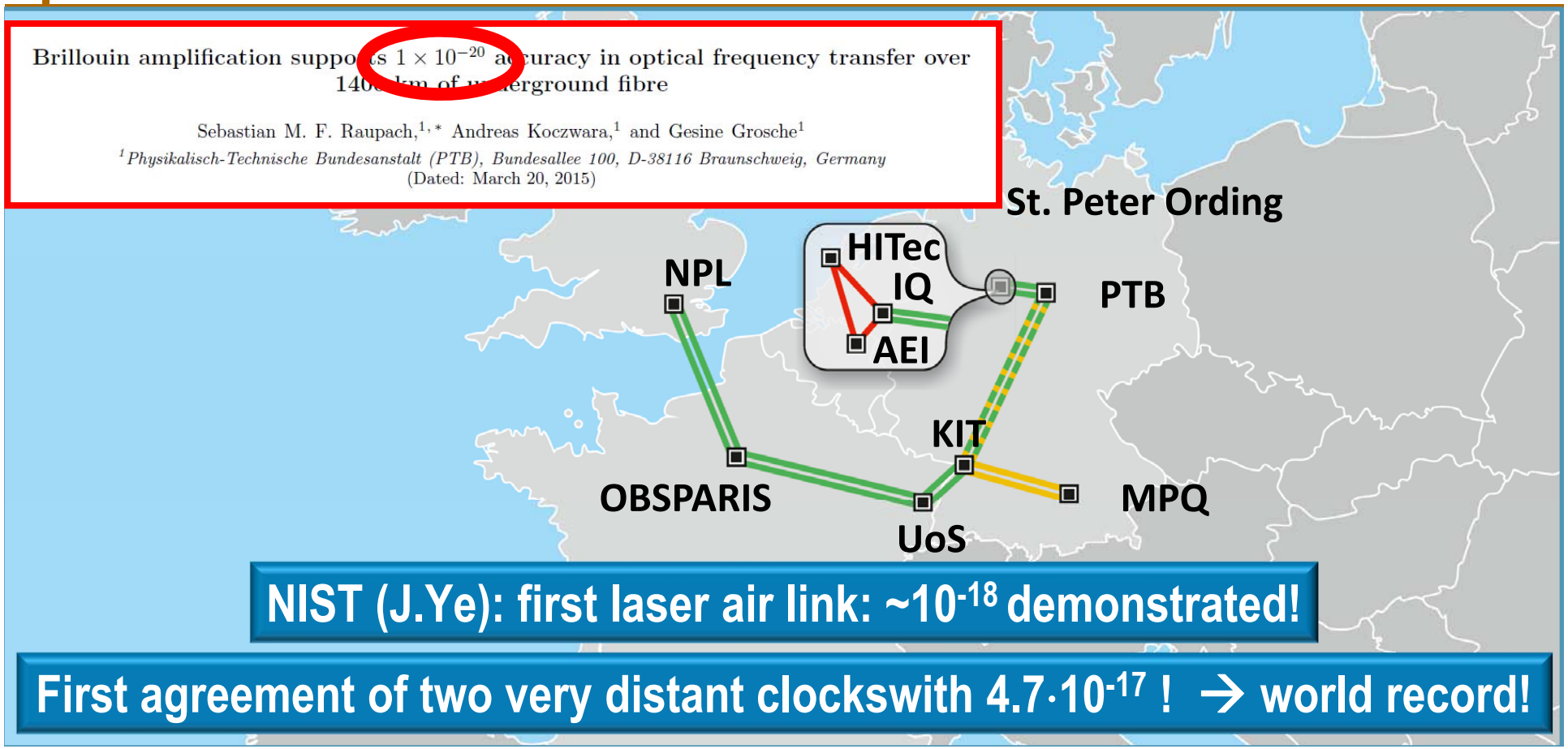
How to compare the clocks

Brillouin amplification supports 1×10^{-20} accuracy in optical frequency transfer over 1400 km of underground fibre

Sebastian M. F. Raupach,[1,*] Andreas Koczwara,[1] and Gesine Grosche[1]

[1] *Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, D-38116 Braunschweig, Germany*

(Dated: March 20, 2015)



NIST (J.Ye): first laser air link: ~10^{-18} demonstrated!

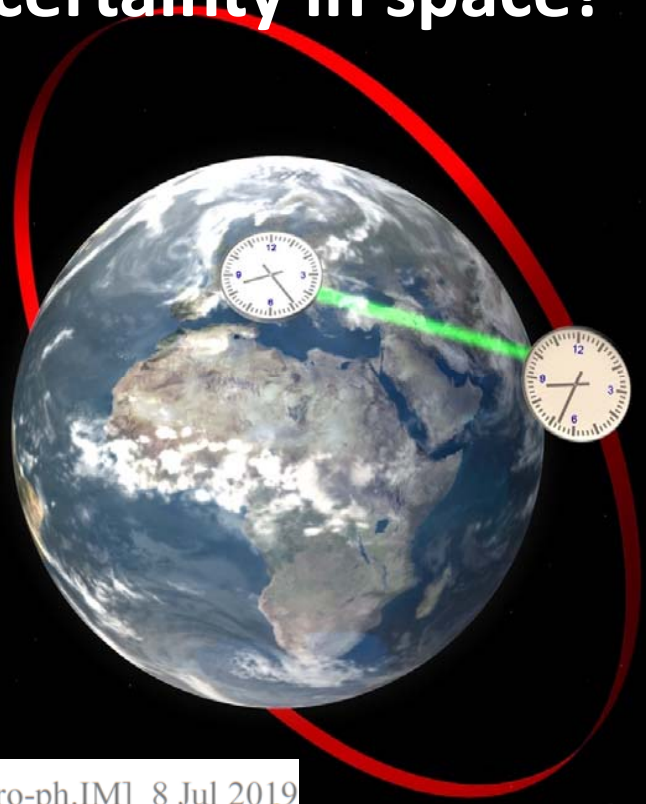
First agreement of two very distant clockswith $4.7 \cdot 10^{-17}$! → world record!

…a dream that will come true…

Optical clocks at ~10^{-19} relative uncertainty in space!

Proposal to ESA in 2016

…a multi-satellite configuration with payload/instruments including strontium optical atomic clocks, strontium atom interferometers, satellite-to-satellite and satellite-to-Earth laser links.



SAGE: A Proposal for a Space Atomic Gravity Explorer

G. M. Tino[1], A. Bassi[2], G. Bianco[3], K. Bongs[4], P. Bouyer[5], L. Cacciapuoti[6], S. Capozziello[7], X. Chen[8], M. L. Chiofalo[9], A. Derevianko[10], W. Ertmer[11], N. Gaaloul[11], P. Gill[12], P. W. Graham[13], J. M. Hogan[13], L. Iess [14], M. A. Kasevich[13], H. Katori[15], C. Klempt[11], X. Lu[16], L.-S. Ma [17], H. Müller[18], N. R. Newbury[19], C. Oates[19], A. Peters[20], N. Poli[1], E. Rasel[11], G. Rosi[1], A. Roura[21], C. Salomon[22], S. Schiller[23], W. Schleich[21], D. Schlippert[11], F. Schreck[24], C. Schubert[11], F. Sorrentino[25], U. Sterr[26], J. W. Thomsen[27], G. Vallone[28], F. Vetrano[29], P. Villoresi[28], W. von Klitzing[30], D. Wilkowski[31], P. Wolf[32], J. Ye[33], N. Yu[34], and M. S. Zhan[35]

2019

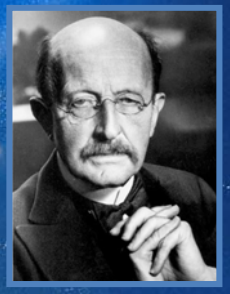
arXiv:1907.03867v1 [astro-ph.IM] 8 Jul 2019

END

A historic event!

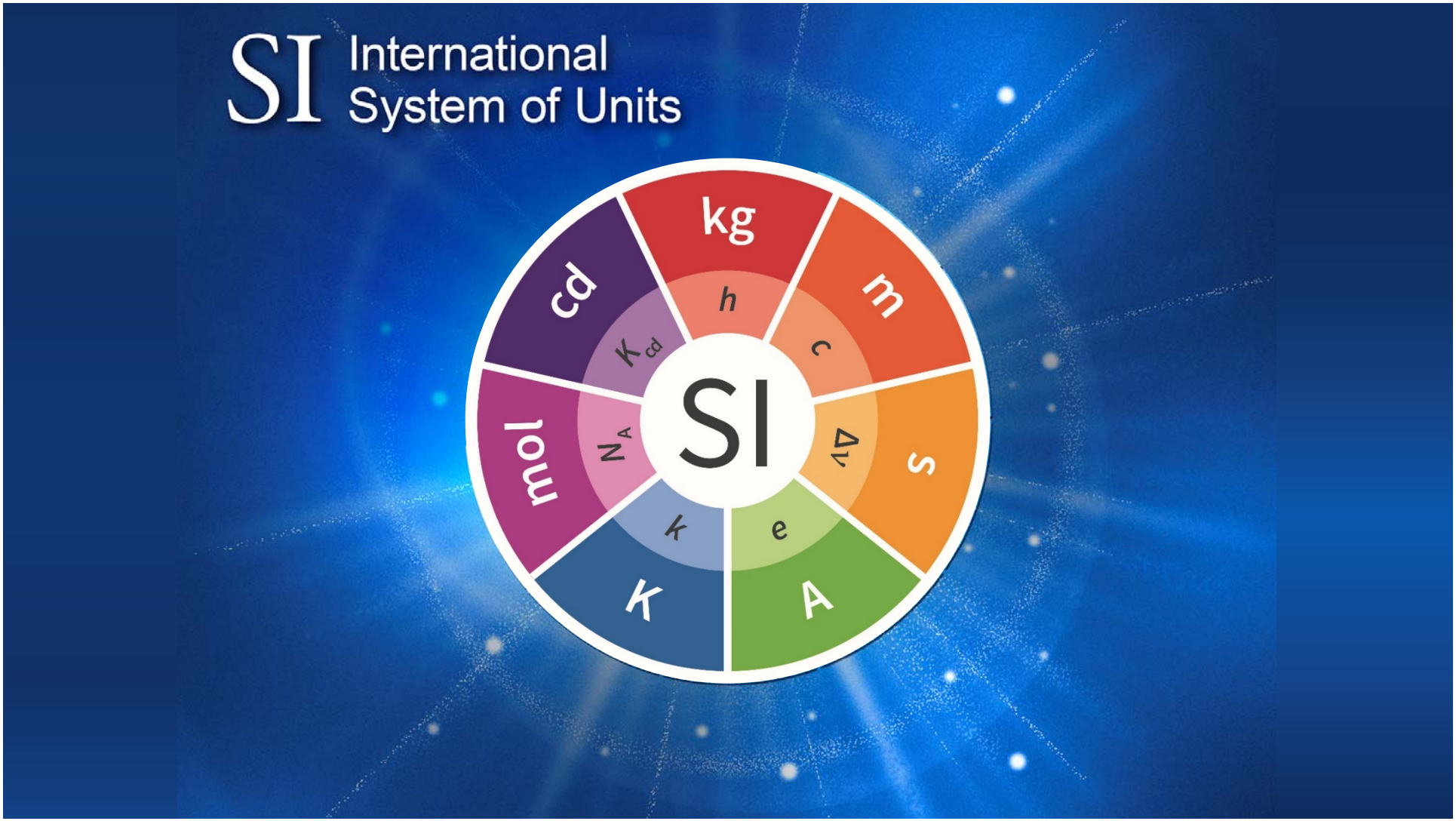

ÉMIRATS ARABES UNIS
ÉTATS-UNIS D'AMÉRIQUE
TURQUIE
JAPON
BRÉSIL
HONGRIE
CROATIE
THAÏLANDE
COLOMB
SI
kg
m
s
A
K
mol
cd
h
c
Δν
e
k
N_A
K_cd

SI International System of Units



…for all times and civilisations…
…throughout the Universe…


SI International System of Units
kg
m
cd
h
c
K
A
From Artefacts to the Quantum SI


SI
International
System of Units
kg
m
s
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K
mol
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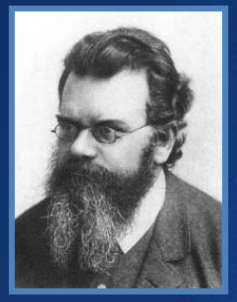
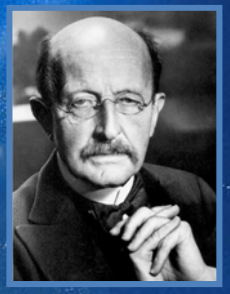
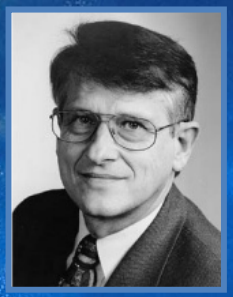
k
NA
Kcd
SI

SI International System of Units

→ Please see the poster!







… for the benefit of mankind!

Merkel, Davos 2019: "…there are things that still work…"

CCTF-CCU Workshop

1.3 Agenda

Draft Agenda for the BIPM Workshop on "Advanced Time and Frequency Transfer: the ultimate frontier for remote comparison methods"

Venue: Pavillon du Mail, BIPM, Sèvres, France.
Start: Thursday 10 October 2019 at 09:00

09.00-09.05 Opening address of the Workshop
[Prof. Joachim Ullrich (PTB) and Dr Davide Calonico (INRIM), Chairs of the Workshop]

09:05 - 09:15 Introduction on CCTF WGATFT activity
[Dr Davide Calonico, INRIM (Italy)]

Session 1: **Chair: *Prof. Joachim Ullrich, (CCU President)***

09.15-10.00 Global quantum communication and precise time frequency dissemination
[Dr Pan Jian-Wei, University of Science and Technology (China)]

10.00-10.45 Optical two-way time and frequency transfer over terrestrial free space links with frequency combs
[Dr Nathan Newbury, NIST (USA)]

10.45-11.30 Tea / Coffee Break

1.3 Agenda

11.30-12.15	Optical time synchronization in the Kepler satellite navigation system *[Prof. Dr Christoph Günther, DLR (Germany)]*
Session 2:	**Chair: *Dr Helen Margolis (NPL)***
12.15-13.00	Intercontinental Frequency link via VLBI *[Dr Mamoru Sekido, NICT (Japan)]*
13.00-14.00	**Lunch**
14.00-14.45	White Rabbit: accurate time and frequency transfer using standard-based technology *[Dr Maciej Lipinski, CERN (Switzerland)]*
14.45-15.30	Coherent optical fibre links: clock comparisons and beyond *[Dr Davide Calonico, INRIM (Italy)]*
15.30-16.00	**Tea / Coffee Break**
Session 3:	**Chair: *Dr Davide Calonico (Chair of CCTF WG-ATFT)***
16.00-18.00	Panel discussion: "Moving forward with remote comparison and dissemination in time and frequency"
18.00	Close of the meeting

CCTF-CCU Workshop

Objective of the workshop:

The Consultative Committee for Time and Frequency Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques (CCTF-WGATFT), in cooperation with the Consultative Committee for Units (CCU), is organizing a workshop with the aim of bringing together different communities to explore the limits of time and frequency transfer in view of a possible redefinition of the second.

Time and frequency transfer methods are key matters within the time and frequency community. The main goal of the workshop is to explore technical advancements in time and frequency transfer as well as related fields outside of this domain.

Time and frequency transfer is widely used in many scientific fields, such as astronomy, telecommunications, space applications, and geodesy, with different levels of relationships with the time and frequency community. The need for high-performing techniques in the time and frequency domain encourages the exploration of these different fields of application to bring together experiences and knowledge.

The first part of the workshop will be dedicated to invited talks and the second part will be followed by a panel discussion on the ultimate frontier for remote comparison methods.

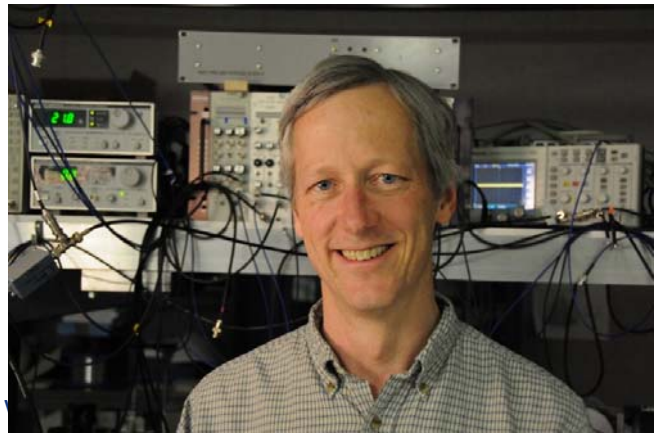
CCTF-CCU Workshop

Proposed discussion topics:

1. Introduction of CCTF-WGATFT activities
2. Optical two-way time and frequency transfer over free space
3. Radio astronomy techniques
4. Synchronization of telecommunication networks
5. Coherent frequency transfer using optical fibres

Featured speakers proposed by the CCU

Jian-Wei Pan *of the University of Science and Technology of* ***China*** *in Hefei.*



Nathan Newbury*, a physicist in* ***NIST*** *PML's Quantum Electronics and Photonics Division*

Prof. Dr. Christoph Günther *(Director of the Institute of Communications and Navigation, Oberpfaffenhofen-Wessling,* ***Germany*** *)*